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Johns-Manville CHEAF Evaluation

Air Pollution Technology, Inc.

Prepared For
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July 1975

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16. ABSTRACT The report gives results of an evaluation of the Johns-Manville CHEAF system for controlling particulate emissions. Fine particulate collection efficiency as a function of dry particle size was computed from data taken on the CHEAF system, a system used to control emissions from a diatomaceous earth calcining and drying process with an overall collection efficiency of 95%. The unit was operating at a capacity of 710 A cu m/min (25,000 acfm), at 63C (145F), with a pressure drop of approximately 50-53 cm (19.5-21 inches) water column. Initial tests showed inlet and outlet size distributions to be identical with a mass mean diameter of 0.82 micrometers A and a geometric standard deviation of 3.9. The data analysis indicates that particle penetration is relatively independent of particle diameter. Further tests revealed that particle growth occurs prior to the CHEAF system. Simultaneous heated and unheated impactor runs provided dried particle size distribution and actual (or wet) size distribution existing inside the scrubber, respectively. Particle growth was then determined, showing that particles grew as much as three times their original size in the submicron range, and less for larger sizes. This particle growth to a more uniform size can explain why penetration is relatively independent of inlet dry particle size.

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JOHNS-MANVILLE CHEAF EVALUATION

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ABSTRACT

Fine particulate collection efficiency as a function of dry particle size has been computed from data taken on Johns-Manville's CHEAF system. The CHEAF controls emissions from a diatomaceous earth calcining and drying process with an overall collection efficiency of 95%. The unit was operating at a capacity of 710 Am^3/min (25,000 ACFM), at 63°C (145°F), with a pressure drop of approximately 50 to 53 cm water column (19.5 to 21 inches W.C.).

Initial test results showed inlet and outlet size distributions to be identical with a mass mean diameter of 0.82 μmA and a geometric standard deviation of 3.9. The data analysis indicates that particle penetration is relatively independent of particle diameter. Further testing revealed that particle growth occurs prior to the CHEAF system. Simultaneous heated and unheated impactor runs provided dried particle size distribution and actual (or wet) size distribution existing inside the scrubber, respectively. Particle growth was then determined and showed that particles grew as much as three times their original size in the submicron range and less for larger sizes. This particle growth to a more uniform size can explain why penetration is relatively independent of inlet dry particle size.

INTRODUCTION

Air Pollution Technology, Inc. (A.P.T.), in accordance with E.P.A. Contract No. 68-02-1496, "Experimental Tests of Novel Fine Particulate Collection Devices", conducted a performance evaluation on Johns-Manville's Cleanable High Efficiency Air Filtration System (CHEAF).

From November 5 through November 15, 1974, the A.P.T. sampling team performed simultaneous inlet and outlet particle sampling measurements on the CHEAF system. After the data were analyzed, further testing was scheduled to determine whether particle growth was occurring prior to the CHEAF system. Therefore, on March 17 through March 21, 1975, the sampling team returned to the test site. Simultaneous heated and unheated cascade impactor tests were performed on the upstream side of the CHEAF to determine whether particle growth occurred due to a condensation nuclei effect.

The results of these series of tests on Johns-Manville's CHEAF are presented in the text.

SOURCE AND CONTROL SYSTEM

The CHEAF system is primarily a rotary air filter system which consists of:

1. Water sprays to wet and clean filter medium
2. Rotary drum containing filter medium
3. Water bath reservoir for cleaning the rotary filter
4. Dual induced blowers used to exhaust the gas to the stack.

Figure 1 is a schematic drawing of this system. Prior to the CHEAF, there is a cyclonic precleaner with water sprays which performs the primary function of removing the majority of large particles in the inlet stream.

The scrubber is installed to control the emissions from a diatomaceous earth calcining and drying process. Emissions enter the precleaner, saturated at a temperature of approximately 75°C, where they are acted upon by water sprays and centrifugal forces which collect the large particles in the stream. The gas exiting the precleaner, saturated at 63°C, then enters the CHEAF. Water sprays again contact the gas as it is drawn through the rotating filter drum where the final cleansing action takes place.

The gas then leaves through the end of the drum while the particles collected on the filter media are washed as the drum rotates into the water bath reservoir. With the help of two blowers, the gas is forced up the stack and flows into the atmosphere as a saturated plume at approximately 60°C. The particle laden water in the reservoir is periodically drained into the plant's main water purification system and then refilled.

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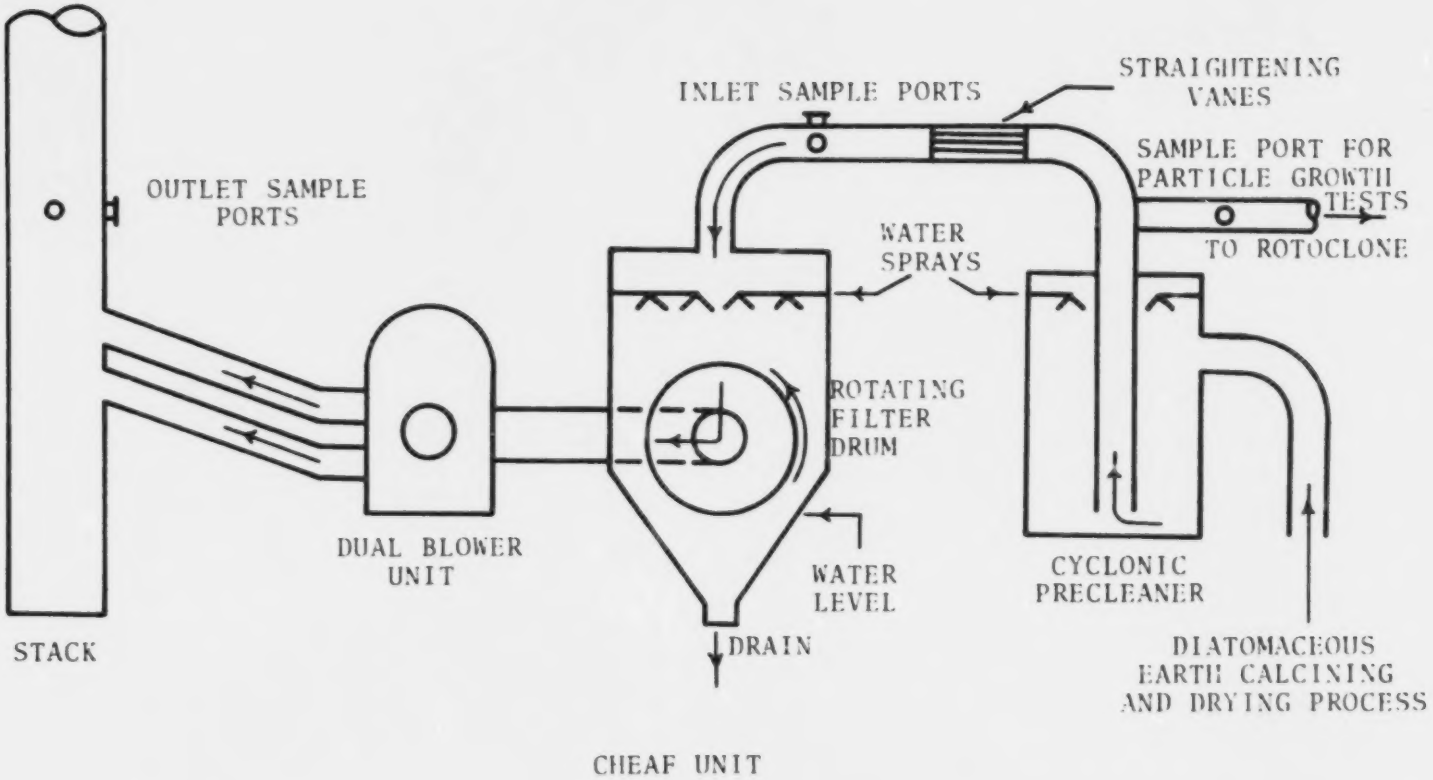

Figure 1 - Schematic drawing of CHEAF system

TEST METHOD

The performance characteristic of the CHEAF was determined by measuring the particle size distribution and mass loading of the inlet and outlet gas sample simultaneously.

For the first series of tests performed in November, 1974, a modified E.P.A. type sampling train with a heated in-stack University of Washington Mark III (U.W.) cascade impactor was used for particle measurements. Figure 2 shows a schematic drawing of this sample train. In-stack filter samples were also taken to obtain total particulate loading and overall efficiency of the system. Due to saturated inlet and outlet streams, an in-stack impaction precutter was attached prior to the cascade impactors and filters in order to prevent water plugging and particle runoff through the impactor stages. Greased aluminum substrates were used in the impactor to prevent particle bounce and minimize wall losses.

An E.P.A. Method 5 Test was also performed to obtain an unbiased sample of the total particulate loading throughout the duct and to determine overall efficiency of the system. Diffusion battery measurements of very fine particulates were attempted, but the apparatus could not cope with the excessive moisture content of the gas.

Gas flow rates were determined by means of a calibrated type "S" pitot tube along with the necessary temperature and pressure measurements. Due to complex ductwork, straightening vanes were inserted upstream of the inlet sample ports in order to cause a uniform flow pattern. The inlet sample port was located between the precleaner

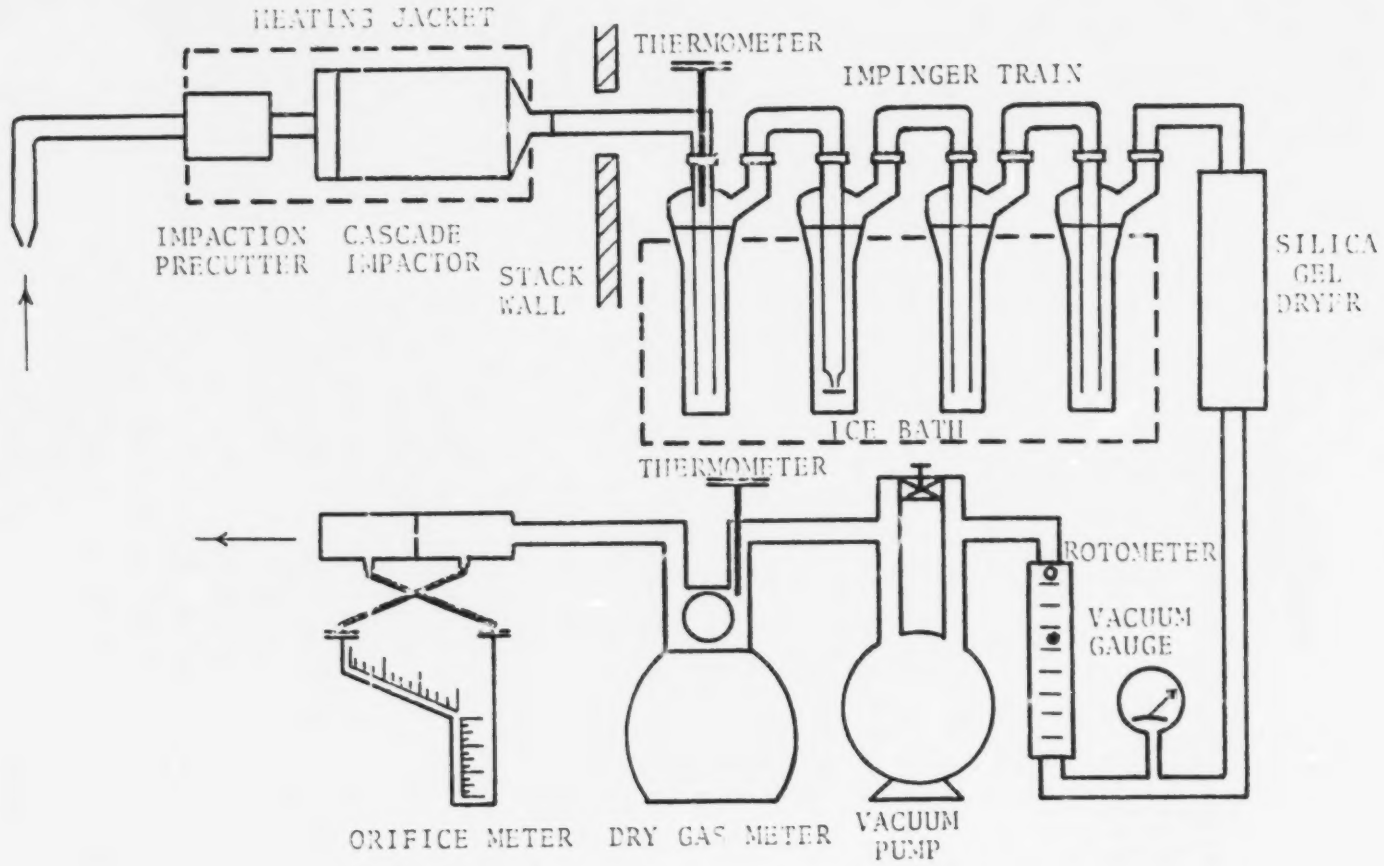

Figure 2 - Modified E.P.A. sampling train with heated precutter and cascade impactor

and the CHEAF unit. The outlet sample port was located on the main stack downstream of the fans. Velocity traverses of the inlet and outlet were performed according to the E.P.A. standards and average velocity points selected for one point sampling. Sample flow rates were measured with the usual E.P.A. train instruments so as to obtain isokinetic sampling. Continuous velocity head and temperature readings were taken during sampling in order to detect any changes in the overall system.

CONDITIONS FOR RUNS

A total of 14 simultaneous inlet and outlet sampling runs were conducted during the first series of tests on the CHEAF system. One-point sampling was employed for all runs except Runs 13 and 14, which were E.P.A. Method 5 Tests. The first five tests were in-stack filter sample runs to determine total particulate loading and overall penetration. Runs 1, 2, and 3 were allowed to heat up to stack temperature before the samples were taken. However, due to heavy water entrainment, even after the precutter, the filters became plugged, causing high pressure drops in the sampling system. These runs were discarded due to the short sample time incurred by the plugging.

In Runs 4 and 5, the precutters and filters were wrapped in electrical heating tape and preheated for approximately thirty minutes before sampling. The temperature was controlled by means of a variac on the heating circuit. The moisture problem was then solved and representative samples were obtained for these runs.

Runs 6 through 12 were heated in-stack impactor runs.

The precutter and impactor were preheated for a period of thirty minutes before sampling.

In Run 6 the outlet impactor collected large amounts of moisture, causing particle runoff through the impactor stages. Therefore test data for the outlet of Run 6 were discarded. The heating temperature was increased to combat this problem.

During Run 7 problems developed in the outlet sample train, which made it necessary to abort the test. No problems occurred on the inlet side.

Run 8 ran smoothly, however, it was discovered that a plant change occurred earlier than scheduled. The plant process changed from an oil fired furnace for drying to a gas fired furnace. The outlet sample was affected by the plant change, whereas the inlet sample was finished prior to the change.

Run 9 was taken in a high velocity region to determine if uniform size distribution existed throughout the inlet and outlet ducts. Large amounts of moisture were found in the outlet impactor. It was decided that the water in the impactor was a direct result of the increased sample flow rate, i.e. increased entrainment of water due to higher jet impaction velocities in the precutter. Previous positions of average flow were taken for the remaining tests.

Runs 10, 11, and 12 were run under identical plant conditions with no moisture problems encountered.

Runs 13 and 14 were E.P.A. Method 5 Tests. Due to high grain loading and a saturated stream at the inlet, sample time at each traverse point was shortened. Results of the Method 5 confirmed the validity of one point sampling for the performance testing of the CHEAF.

PARTICLE GROWTH

Further testing was performed from March 17 through March 21, 1975 to determine if particle growth occurred in the cyclonic precleaner prior to the CHEAF. The CHEAF was inoperable at the time of testing and therefore was bypassed. Testing was done after the cyclonic precleaner and prior to a rotoclone (See schematic of CHEAF system).

In the determination of the extent of particle growth, two identical U.W. cascade impactors were used side by side to sample the effluent. Both impactors were preceded by identical impaction precutters to prevent moisture entrainment. The final filters of both impactors were removed and located in separate filter holders following the impactor. Then, to sample the dry particle size, one impactor and its final filter were heated in order to drive off any condensate on the particle. The actual (or wet) particle size was measured by the unheated impactor with only its final filter heated to prevent moisture build-up. The same modified E.P.A. sampling trains were used for the particle growth tests. Figures 3 and 4 show schematics of the dry particle size and wet particle size sampling trains, respectively.

The dry particle size sampling was comparable to the first series of tests done on the CHEAF in which both inlet and outlet impactors were heated.

Sampling flow rates again were measured with the usual E.P.A. train instruments to obtain isokinetic sampling. The inlets of both nozzles were set at nearly the same position to assure identical aerosol conditions and the sample flow rates through both impactors were identical.

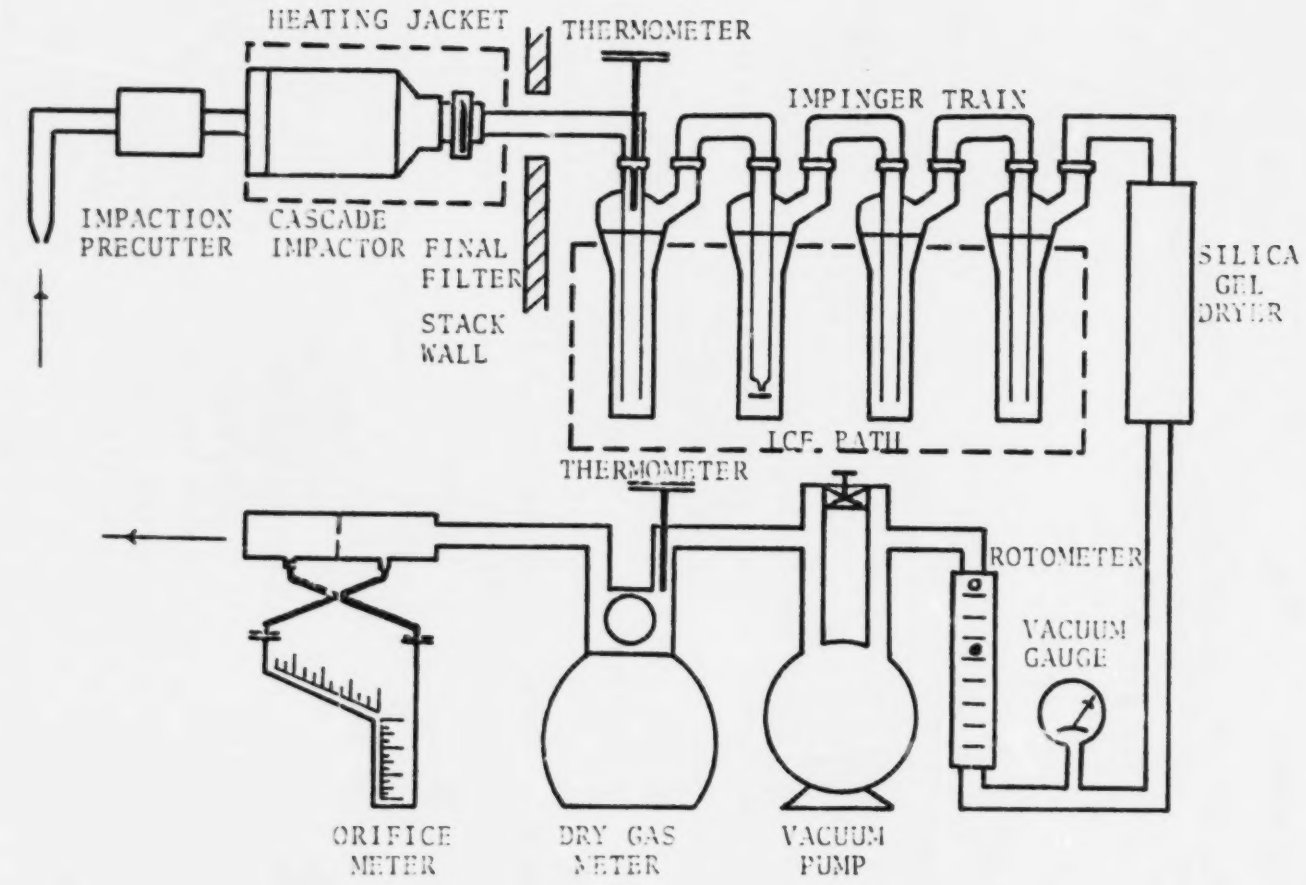

Figure 3 - Modified E.P.A. sampling train with precutter and heated cascade impactor with attached final filter

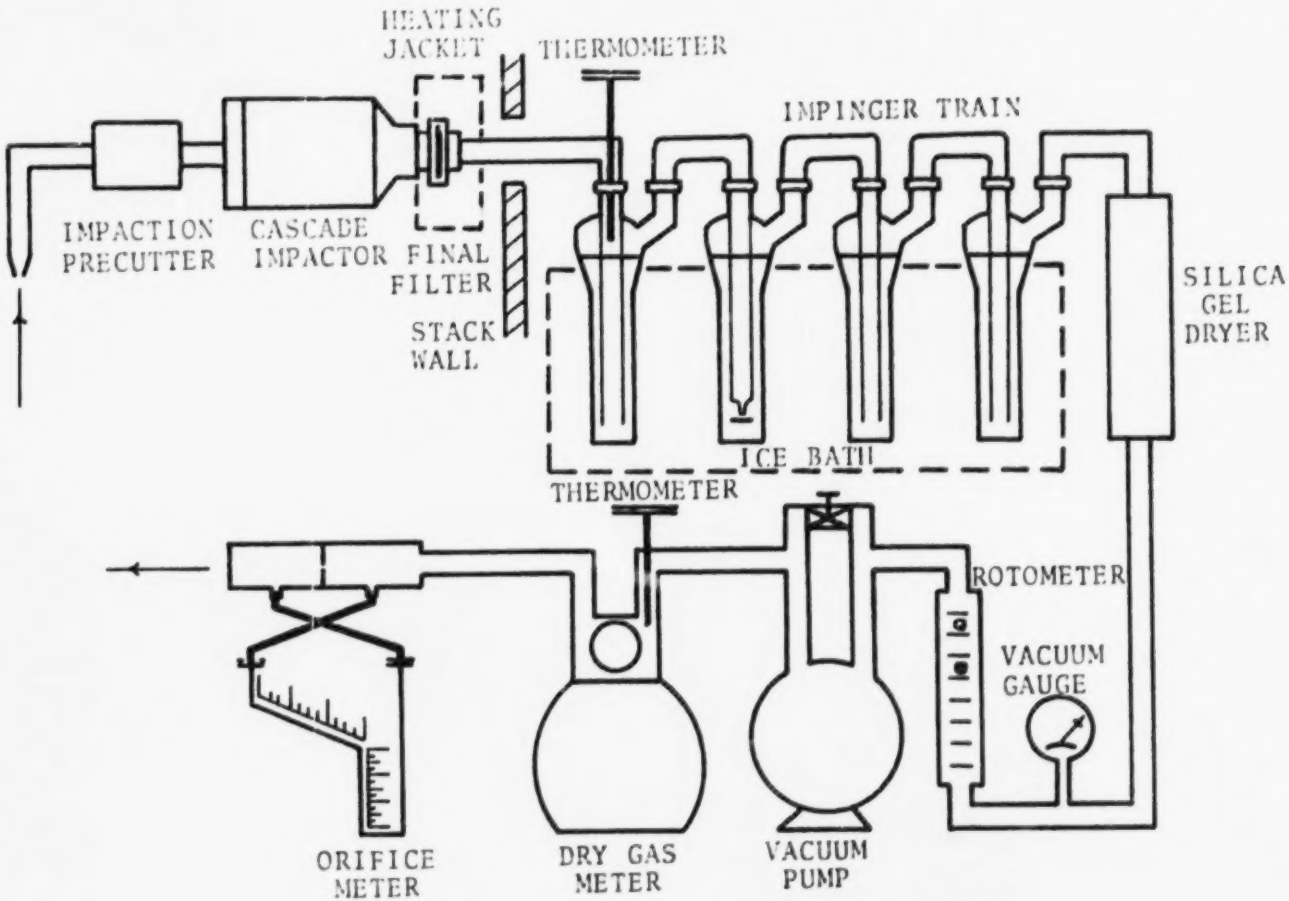

Figure 4 - Modified E.P.A. sampling train with precutter, cascade impactor, and heated final filter

Five test runs (Runs 15 through 19) were performed for particle growth determination. Large amounts of moisture were accumulated in Runs 15 and 16 on the initial stages of the impactors which caused stage flooding and particle run off. After an investigation of the inside of the duct, it was discovered that the sample nozzles were directly downstream of a central water spray nozzle. The spray nozzle was turned off and Runs 17, 18, and 19 were taken. Both impactors on Run 17 were loaded heavily, which resulted in plugging several jet holes on the lower stages. Although visual inspection revealed similar loading characteristics, as in Runs 18 and 19, the data were considered invalid due to the jet hole plugging. Sample times for Runs 18 and 19 were decreased and ideal loadings were obtained. Results of all test runs are presented in the Particle Data Section of this report.

OPERATING CONDITIONS

The CHEAF operating conditions during the initial test period were as follows:

1. Gas flow rates and related parameters as shown in tabulation below:

DUCT	INLET	OUTLET
Temperature	63°C	60°C
Velocity	12.2 m/sec	5.8 m/sec
Am^3/min	710	Same as inlet
ACFM	25,000	Same as inlet
DN m^3/min @0°C	480	Same as inlet
DCFM @70°F	18,300	Same as inlet
Vol. $\%H_2O$ vapor	17	17
Pressure	-7.6 cm W.C.	0.2 cm W.C.

2. Water flow rate to the CHEAF system was reported as approxmiately 0.053 m^3/min (14 GPM).
3. Pressure drop through the CHEAF system was approxmiately 48-53 cm W.C. (19-21 inches W.C.) during the test period.
4. The L/G ratio during the test period was approximately 0.11 ℓ/m^3.

PARTICLE DATA

Four separate sets of data were obtained from the CHEAF system during the first test period. The first two data sets (Runs 4 and 5 and Runs 6, 7, and 8) were obtained at identical one-point sampling locations and identical plant conditions. The third set of data points (Runs 9 through 12) was obtained at the previous sample locations but the plant was switched from an oil-fired to a gas-fired drying process. Finally, the fourth data set was obtained from two E.P.A. Method 5 Tests (Runs 13 and 14).

All particle data for Runs 4 through 14 are given in Appendix A. Particle concentration and sample flow rates for Runs 4 and 5 are given in Table A-1. Particle concentration and size for Runs 6, 7, and 8 are tabulated in Tables A-2 through A-4. Size distribution for these runs is shown in Figure 5. Runs 9 through 12 are represented in Tables A-5 through A-8, while the size distribution plots for these runs are illustrated in Figure 6. Finally, the particle concentrations for the last data set, Runs 13 and 14 (Method 5) are presented in Table A-9.

In this report, the symbol "d_{pa}" refers to aerodynamic diameter, which is equal to the particle diameter (d_p) in microns (μm) times the square root of the particle density (ρ_p) in grams per cubic centimeter (g/cm^3) times the square root of the Cunningham slip correction factor (C'). The symbol "μmA" represents the units of aerodynamic size.

$$d_{pa} \equiv d_p \left(\rho_p C' \right)^{1/2}, \ \mu mA \qquad (1)$$

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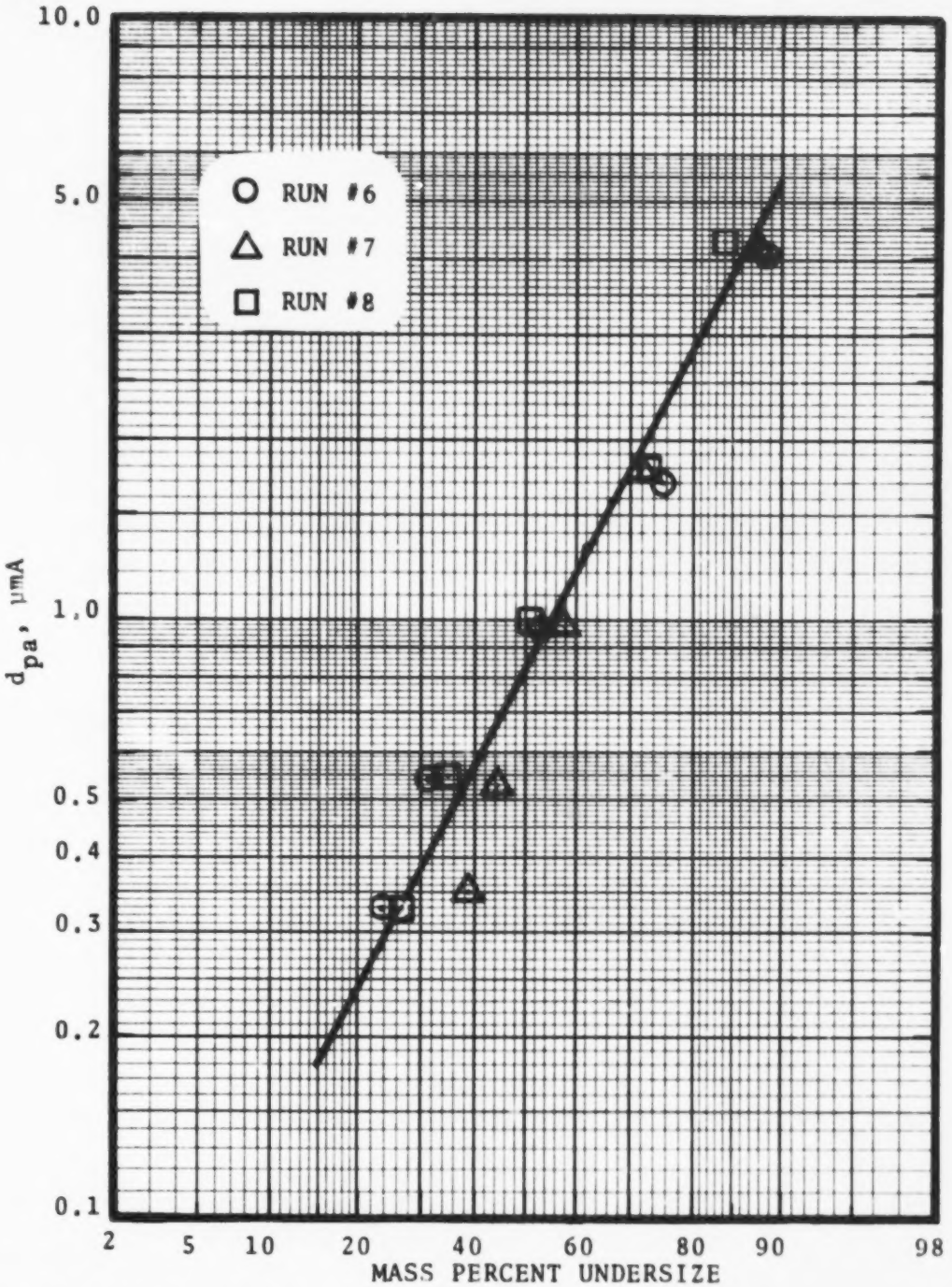

Figure 5 - Inlet size distributions

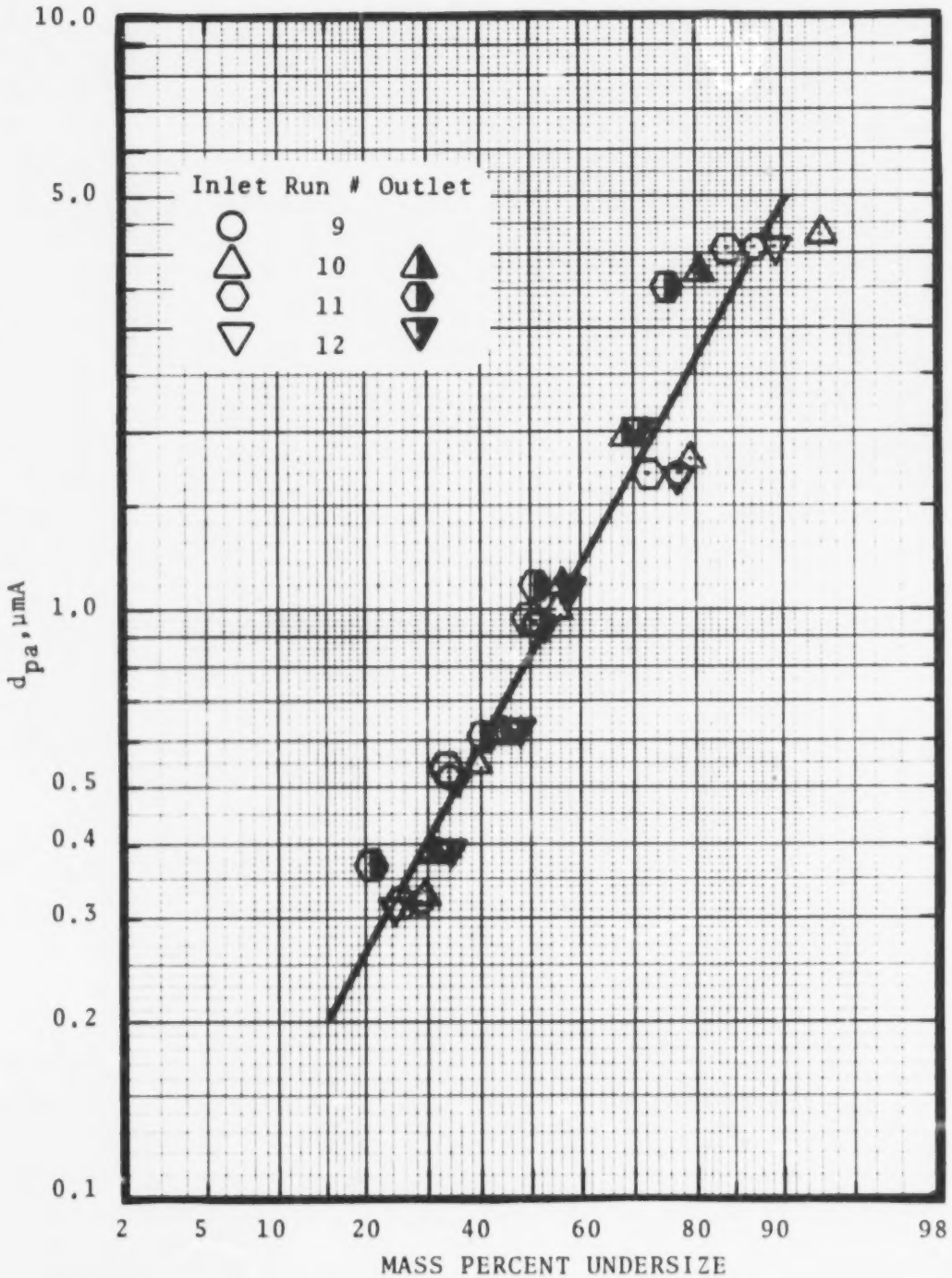

Figure 6 - Inlet and outlet size distributions

As seen in Figures 2 and 3, the following aerodynamic mass median diameters and standard deviations were found:

RUN NO.	INLET		OUTLET	
	d_{pg}, μmA	σ_g	d_{pg}, μmA	σ_g
6, 7, 8	0.82	4.2	--	--
9, 10, 11, 12	0.82	3.9	0.82	3.9

Average sample times for the inlet were five to ten minutes depending on the grain loading while the outlet sample time averaged approximately forty-five minutes.

Isokinetic sampling was undertaken for all the test runs, however, isokinetic conditions are not that crucial for sampling fine particles. For example, the error caused by sampling 4 μmA particles at a velocity 50% higher or lower than the gas stream velocity would only be about 2 or 3% of the concentration.

Single point sampling is also generally sufficient when measuring fine particle size and concentration. The fine particles will be well distributed in the gas stream, except in cases where streams with different particle concentrations have not had sufficient time to mix. To illustrate that one point sampling is sufficient for fine particles, we may note that Stokes stopping distance of a 3 μmA particle with an initial velocity of 15 m/sec (50 ft/sec) is about 0.04 cm (0.016 inches) and for a 1 μmA diameter particle is one ninth of that. Since the stopping distance is the maximum that a particle can be

displaced from a gas streamline by going around a right angle bend, it becomes apparent that fine particle distribution in the gas stream will be negligibly affected by flow direction changes.

Particle data for the particle growth tests are given in Appendix A also. Particle concentration and size for Runs 17, 18, and 19 are given in Tables A-10 through A-12. Size distributions for Runs 18 and 19 are given in Figures 7 and 8, in which the particle size (wet or dry) is plotted against the cumulative mass percentage of dry solids. The amount of particle growth is then related to the difference between the two curves at each mass percent solids. These figures show that the small particles grow proportionately more than the large ones; as would be the case if the particles acted as condensation nuclei with a small fraction of soluble material in a super-saturated gas. The aerodynamic mass mean diameter of the dry particle size is almost doubled after particle growth occurs. Aerodynamic mass median diameters and standard deviations for Runs 18 and 19 are given below:

RUN NO.	DRY PARTICLE SIZE		WET PARTICLE SIZE	
	d_{pg}, μmA	σ_g	d_{pg}, μmA	σ_g
18	1.4	3.2	2.2	2.3
19	1.1	3.1	2.1	2.0

The impaction precutters used during the particle growth tests had cut diameters of approximately 7 microns aerodynamic. This explains the effect the precutters

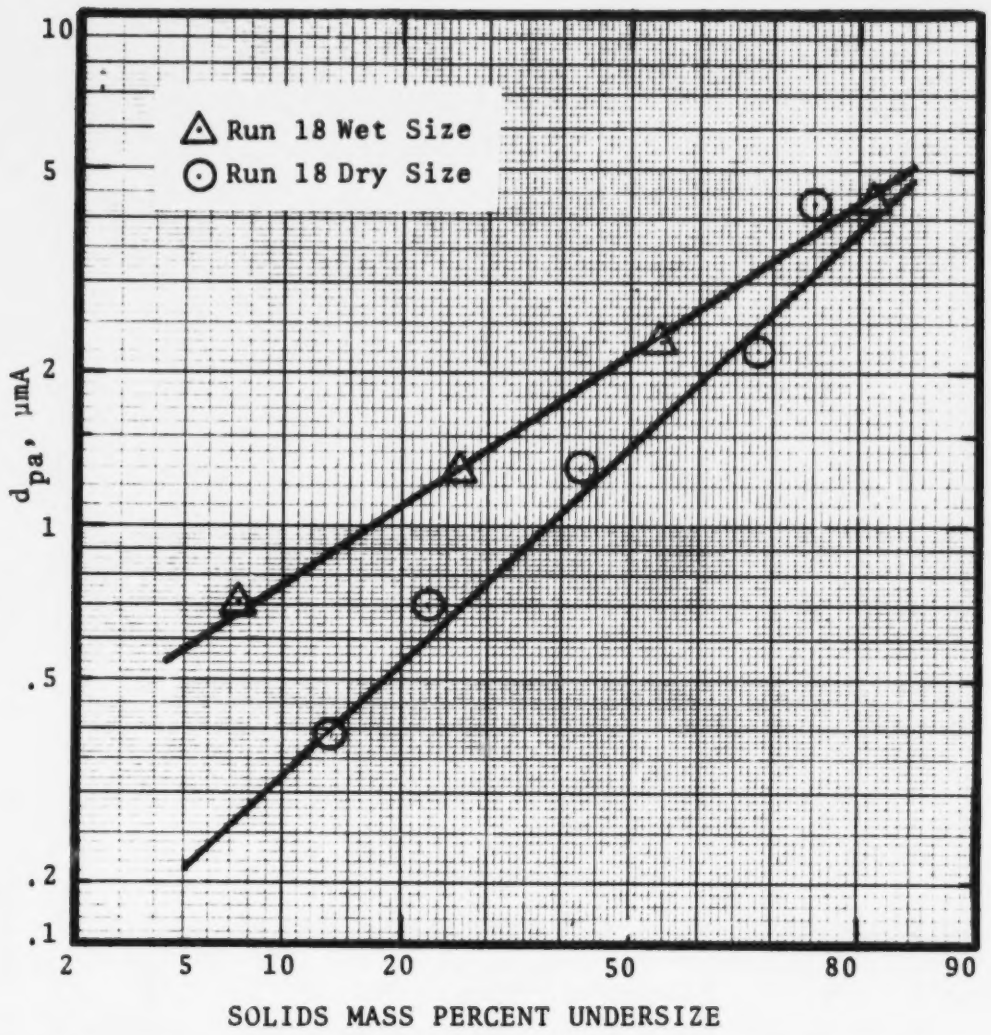

Figure 7 - Run 18 wet and dry size distributions

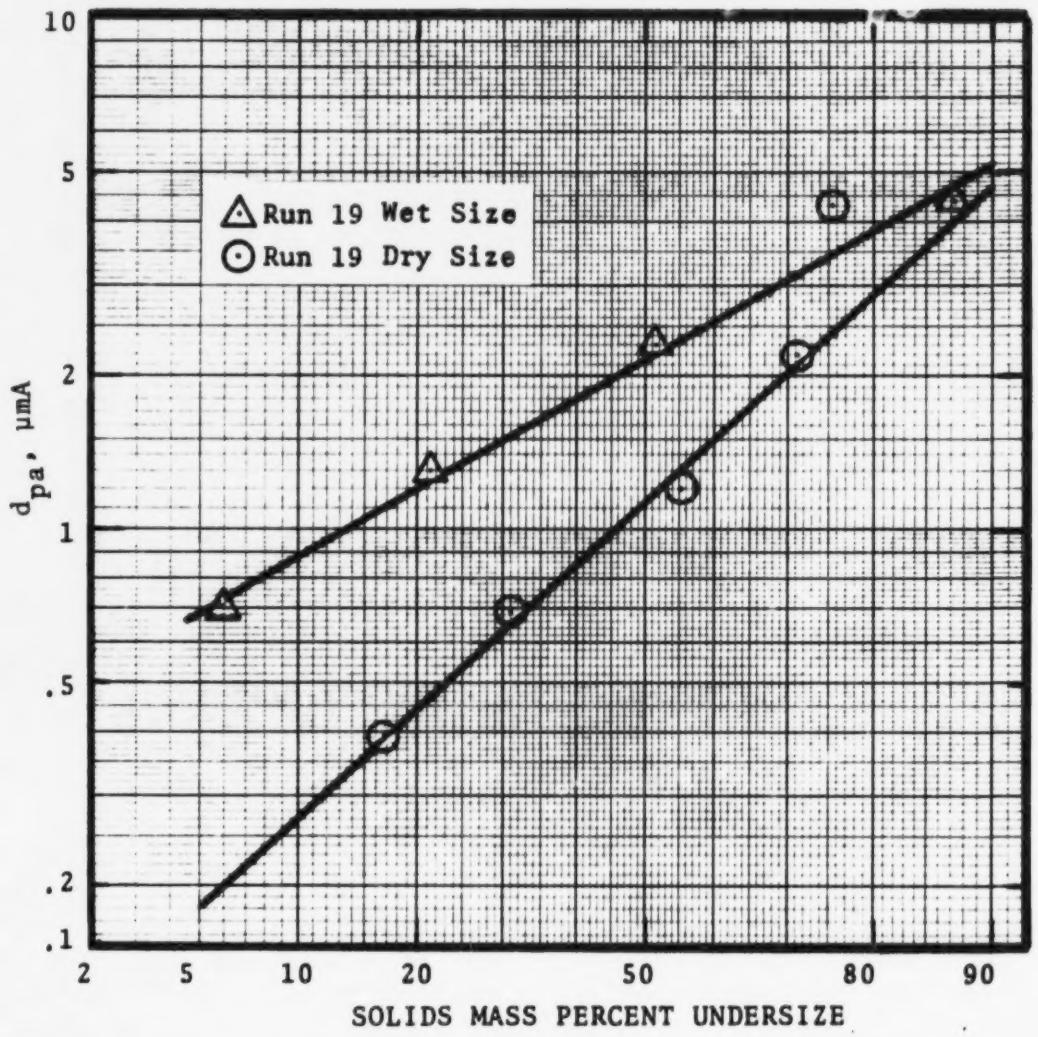

Figure 8 - Run 19 wet and dry size distributions

have on the size distribution curves. If the precutters had not been used, more particles and therefore more weight would have been collected on the first three stages of the U.W. impactor. This would tend to shift the upper data points downward and in line with the straight line curves drawn. See Tables A-11 and A-12 for data on particles larger than 10 μmA diameter.

PARTICLE PENETRATION

Cumulative mass concentration versus aerodynamic particle diameter was plotted for Runs 10, 11, and 12 and placed in Appendix B. From the analysis of these curves (Figures B-1 through B-6), and noting that the inlet and outlet size distributions are identical, we can conclude that particle penetration is relatively independent of particle diameter. The penetration is approximately 5% throughout the size distribution.

Particle penetration versus dry particle size for Runs 10, 11, and 12 are plotted in Figures B-7 through B-9. The penetration curves are flat and show a relatively constant penetration over the particle size.

Particle growth appears to have a beneficial effect on particle penetration, especially in the submicron range. Particles in this range grow up to as much as three times their original diameter. They, in turn, are more easily captured by inertial impaction and thus a lower particle penetration occurs. Instead of particle penetration increasing for submicron particles, it remains constant due to the particle growth and thus the penetration curves appear flat.

It is important to characterize the CHEAF performance in such a way that it can be compared to other devices or evaluated for possible use for the collection of particles which do not grow. In order to do this, the penetration data obtained for dried particles were treated in the following way:

1. Determine the wet particle diameter to which a dry particle would grow by means of Figures 7 and 8.

2. For a typical scrubber, find the cut diameter which would be consistent with the penetration versus particle diameter data obtained experimentally and converted to "wet" size by step 1 above. The cut diameter for an equivalent scrubber is computed by means of equation (2), which is appropriate for the inertial impaction collection regieme.

$$Pt = \exp\left[-Ad^2_{pa}\right] \qquad (2)$$

3. Compute the scrubber "equivalent" cut diameter corresponding to a given penetration for a dried particle size by means of the relationships found in steps 1 and 2.

The results of the procedure described above are as shown in the tabulation below:

Dried d_{pa}, µmA	Pt.*	Wet d_{pa},** µmA	$\frac{d_{pa}}{d_{pc}}$***	Predicted d_{pc}, µmA
0.5	0.065	1.2	2.0	0.6
0.7	0.05	1.5	2.1	0.71
1.0	0.046	1.9	2.1	0.9
2.0	0.045	2.9	2.1	1.4

Notes: *Average penetration for Runs 10, 11 & 12
**Average wet diameter for Runs 18 & 19
***Computed by equation (2)

The predicted cut diameters are not constant so it is necessary to use some judgement in interpreting the results of the computation above. As can be seen in Figures B-7, B-8, and B-9, the "dry" penetrations for the three runs are in close agreement for dry particle diameters larger than 0.8 μmA. The cut diameter corresponding to dry particles larger than 0.8 μmA could be as low as 0.7 to 0.9 μmA and an estimate of d_{pc} = 0.8 μmA seems reasonably optimistic in view of the poorer performance for larger particles. Thus, a typical scrubber, such as a venturi, which had an 0.8 μmA cut diameter would give about the same performance on wet particles as the CHEAF.

OPACITY

Plume opacity of the CHEAF system averaged 10% during the test period. The visual observation method was used for all opacity measurements which were taken by a Johns-Manville employee who was a certified observer trained in a California Air Resources Board "Smoke School". According to the observer, visible measurements were taken on a hill above the stack approximately fifteen meters away. A detached plume enabled the observer to read opacity at the stack.

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ECONOMICS

Cost data for the CHEAF were not provided by the manufacturer. According to the manufacturer, technology is not yet sufficiently well established that reliable capital and operating costs can be presented.

The CHEAF system uses inertial impaction mechanisms for collection of particles. Figure 9 represents a plot of pressure drop (cm W.C.) and theoretical power ($KW/Mm^3/min$) versus aerodynamic cut diameter. The CHEAF system with a pressure drop of 50 cm W.C. and a cut diameter of about 0.8 μmA can be compared to different scrubber systems using Figure 9. "F" is froth density for the plates, "f" is an empirical constant which is influenced by particle wettability and other factors for venturis,"d_h" equals the sieve plate hole diameter, and "d_c" is the packing diameter.

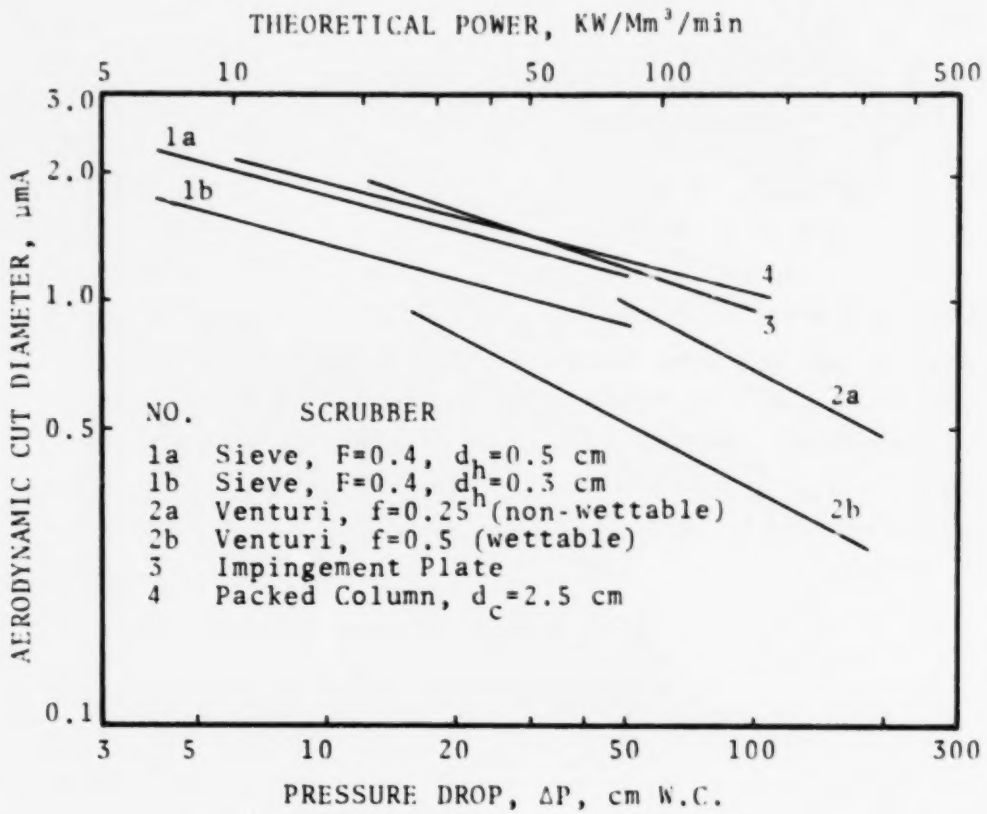

Figure 9 - Theoretical power and pressure drop vs. aerodynamic cut diameter

MANUFACTURER'S DESCRIPTION OF DEVICE

CHEAF is a patented system for removal of fine particulate matter from air or gas streams. It was developed through R&D efforts of the Johns-Manville Corporation over the past three years. The system provides continuous filtration through polymeric foam media at high velocities. These velocities bring into dominant effect the inertial impaction mechanisms of particle capture and make feasible relatively compact designs.

The CHEAF unit tested by A.P.T. was tailored to the specific needs for control of emissions from the diatomaceous earth processing plant. In this case the controlling regulation is that requiring plume opacity no greater than 20 percent. It was assumed that reduction of dust loading of the plume to about 50 mg/Am^3 would suffice, but some safety factor was built into the device. Its efficiency could readily be increased should an increase in average dust load from the plant or a change in control regulations engender the need. While this system was operating with pressure drops of 50-53 cm W.C. (19.5 to 21 inches W.C.) in the course of the A.P.T. testing program, it has since been modified (by simple changes in filter medium configuration and in face velocity) to reduce the pressure drop to 43 cm (17 inches).

It should be noted that no mist eliminator was employed in the unit as tested. Such a device will be installed in some additional units now under construction. This should reduce the amount of condensed moisture reaching the stack and collect that portion of solid particulate retained in the collected water drops.

The precleaner mentioned in the body of the report is a low-pressure-drop, wet cyclonic separator which had been used as one stage of the dust control system employed before installation of the CHEAF unit. It was deemed appropriate to leave it in the train as protection against excessive thermal excursions, which may occur occasionally in the diatomite-processing line. While performing this function it does collect some of the coarser particulate present and, thus, relieves the CHEAF of some of the dust loading. The CHEAF has been operated with the precleaner deactivated.

OPERATIONAL PROBLEMS

The CHEAF, although a temporary installation, operated very smoothly during the testing period, however, plant process shutdowns delayed testing on schedule. The major problem in this CHEAF installation is operating under a corrosive atmosphere. Residual chlorides from the diatomaceous earth process and sulfates from the oil-fired furnace, together with a saturated gas stream, tend to accelerate corrosion on the internal parts of the CHEAF.

Carbon steel fans in both of the blowers were gradually eroding, causing an imbalance in the units. This, in turn, caused considerable vibrational problems and excessive wear on the motors' main shaft bearings.

CONCLUSIONS

According to the test results obtained on the CHEAF (Cleanable High Efficiency Air Filter) system, particle penetration is relatively independent of dry particle size. Penetration is approximately 5% with the mean dry particle diameter equal to 0.82 μmA. This aerodynamic diameter is equivalent to an actual size of 0.45 microns (μm) when the density for diatomaceous earth is assumed to be 2.5 g/cm^3.

The CHEAF appears to be a reasonably efficient device for fine particulate control of saturated emissions from a diatomaceous earth calcining and drying process. Particle growth occurring in the precleaner prior to the CHEAF is beneficial to the fine particle collection efficiency of the system to a certain extent. Particle growth tests could not be performed on the outlet of the CHEAF and therefore the extent to which particle growth increases collection efficiency was predicted but not quantitatively confirmed.

Results from the E.P.A. Method 5 Tests are comparable to the results obtained in the one-point total mass loading tests. We can therefore conclude that one-point sampling of the CHEAF system was sufficient and representative for the testing performed.

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APPENDIX A

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Table A-1. INLET AND OUTLET TOTAL PARTICULATE LOADING FOR RUNS 4 and 5

RUN NUMBER	INLET (mg/DNm^3)	OUTLET (mg/DNm^3)	$\overline{Pt}$ %	SAMPLE VOLUMES DNm^3	
				IN	OUT
4	492	22.5	4.6	0.061	0.57
5	372	31.3	8.4	0.081	0.57

Table A-2. INLET AND OUTLET SAMPLE PARTICLE DATA FOR RUN #6

IMPACTOR STAGE NUMBER	INLET		OUTLET	
	M_{cum} (mg/DNm^3)	d_{pc} (μmA)	M_{cum} (mg/DNm^3)	d_{pc} (μmA)
Precutter	401		High Moisture Entrainment Causing Particle Runoff- Outlet Data Invalidated	
1	356	20		
2	356	8.9		
3	356	4.0		
4	356	1.7		
5	304	0.97		
6	214	0.54		
7	126	0.33		
Filter	95.4	-		
Sample Volume (DNm^3)	0.20			

M_{cum} = Cumulative mass collected on that stage and those below

d_{pc} = Cut diameter (aerodynamic) for that stage

μmA = Microns, aerodynamic = $d_p(C'\rho_p)^{1/2}$

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Table A-3. INLET AND OUTLET SAMPLE PARTICLE DATA FOR RUN #7

IMPACTOR STAGE NUMBER	INLET		OUTLET	
	M_{cum} (mg/DNm^3)	d_{pc} (μmA)	M_{cum} (mg/DNm^3)	d_{pc} (μmA)
Precutter	569			
1	501	20		
2	501	9.0	Outlet Sample	
3	501	4.2	Train Malfuntion-	
4	500	1.8		
5	439	0.98		
6	329	0.53	No data obtained	
7	252	0.35		
Filter	225	-		
Sample Volume (DNm^3)	0.095			

Table A-4. INLET AND OUTLET SAMPLE PARTICLE DATA FOR RUN #8

IMPACTOR STAGE NUMBER	INLET		OUTLET	
	M_{cum} (mg/DNm^3)	d_{pc} (μmA)	M_{cum} (mg/DNm^3)	d_{pc} (μmA)
Precutter	423	21		
1	355	9.1	Change in Plant	
2	355	4.3	Operation-	
3	355	1.8		
4	355	1.0		
5	309	0.55	Outlet Data	
6	216	0.33	Invalidated	
7	148	-		
Filter	114			
Sample Volume (DNm^3)	0.077			

Table A-5. INLET AND OUTLET SAMPLE PARTICLE DATA FOR RUN #9

IMPACTOR STAGE NUMBER	INLET		OUTLET	
	M_{cum} (mg/DNm³)	d_{pc} (μmA)	M_{cum} (mg/DNm³)	d_{pc} (μmA)
Precutter	303		Particle Runoff Due to Moisture Accumulation- Outlet Data Invalidated	
1	272	20		
2	270	8.5		
3	268	4.1		
4	265	1.7		
5	235	0.95		
6	154	0.52		
7	103	0.32		
Filter	87	-		
Sample Volume (DNm³)	0.11			

Table A-6. INLET AND OUTLET SAMPLE PARTICLE DATA FOR RUN #10

IMPACTOR STAGE NUMBER	INLET		OUTLET	
	M_{cum} (mg/DNm³)	d_{pc} (μmA)	M_{cum} (mg/DNm³)	d_{pc} (μmA)
Precutter	320		21.1	
1	298	21	17.3	23
2	298	9.1	17.3	10
3	298	4.3	17.2	3.8
4	298	1.8	17.0	2.0
5	254	1.0	14.6	1.1
6	178	0.55	11.9	0.62
7	127	0.33	9.5	0.39
Filter	95	-	6.5	-
Sample Volume (DNm³)	0.082		0.61	

Table A-7. INLET AND OUTLET SAMPLE PARTICLE DATA FOR RUN #11

IMPACTOR STAGE NUMBER	INLET		OUTLET	
	M_{cum} (mg/DNm^3)	d_{pc} (μmA)	M_{cum} (mg/DNm^3)	d_{pc} (μmA)
Precutter	266		15.1	
1	225	20	11.3	23
2	225	8.8	11.3	10
3	225	4.1	11.3	3.7
4	224	1.7	11.3	1.9
5	193	0.96	9.8	1.1
6	133	0.53	7.7	0.61
7	91	0.32	6.3	0.35
Filter	68		3.1	
Sample Volume (DNm^3)	0.12		0.64	

Table A-8. INLET AND OUTLET SAMPLE PARTICLE DATA FOR RUN #12

IMPACTOR STAGE NUMBER	INLET		OUTLET	
	M_{cum} (mg/DNm^3)	d_{pc} (μmA)	M_{cum} (mg/DNm^3)	d_{pc} (μmA)
Precutter	265		17.6	
1	238	20	12.7	23.2
2	238	8.8	12.7	10.3
3	238	4.1	12.7	3.8
4	237	1.7	12.7	2.0
5	203	0.96	11.9	1.1
6	139	0.53	9.9	0.62
7	89	0.32	8.3	0.39
Filter	66		6.0	
Sample Volume (DNm^3)	0.089		0.64	

Table A-9. INLET AND OUTLET TOTAL PARTICULATE LOADING FOR RUNS #13 AND #14 USING E.P.A. METHOD 5

RUN NUMBER	INLET (mg/DNm^3)	OUTLET (mg/DNm^3)	$\overline{Pt\%}$	SAMPLE VOLUMES DNm^3	
				IN	OUT
13	466	20.6	4.4	0.058	0.62
14	389	20.8	5.3	0.053	0.64

Table A-10. DRY AND WET SAMPLE PARTICLE DATA FOR RUN #17

IMPACTOR STAGE NUMBER	DRY PARTICLE SIZE		WET PARTICLE SIZE	
	M_{cum} (mg/DNm^3)	d_{pc} (μmA)	M_{cum} (mg/DNm^3)	d_{pc} (μmA)
Precutter	686		475	
1	660	26.7	475	26.3
2	660	11.8	449	11.5
3	660	4.5	449	4.3
4	634	2.3	449	2.2
5	554	1.4	343	1.3
6	449	0.72	71.3	0.70
7	317	0.42	31.7	0.39
Filter	290		5.3	
Sample Volume (DNm^3)	0.09		0.14	

Table A-11. DRY AND WET SAMPLE PARTICLE DATA FOR RUN #18

IMPACTOR STAGE NUMBER	DRY		WET	
	M_{cum} (mg/DNm^3)	d_{pc} (µmA)	M_{cum} (mg/DNm^3)	d_{pc} (µmA)
Precutter	467		369	
1	394	26.3	369	26.6
2	369	11.5	341	11.7
3	369	4.3	344	4.4
4	344	2.2	295	2.3
5	320	1.3	201	1.3
6	202	0.70	95.9	0.71
7	108	0.39	27.1	0.39
Filter	64			
Sample Volume (DNm^3)	0.059		0.058	

Table A-12. DRY AND WET SAMPLE PARTICLE DATA FOR RUN #19

IMPACTOR STAGE NUMBER	DRY		WET	
	M_{cum} (mg/DNm^3)	d_{pc} (µmA)	M_{cum} (mg/DNm^3)	d_{pc} (µmA)
Precutter	295		194	
1	219	25.8	194	26.6
2	219	11.3	189	11.7
3	219	4.3	187	4.4
4	216	2.2	170	2.3
5	204	1.2	101	1.3
6	160	0.69	41.8	0.71
7	88.6	0.39	11.8	0.41
Filter	49.2			
Sample Volume (DNm^3)	0.080		0.077	

APPENDIX B

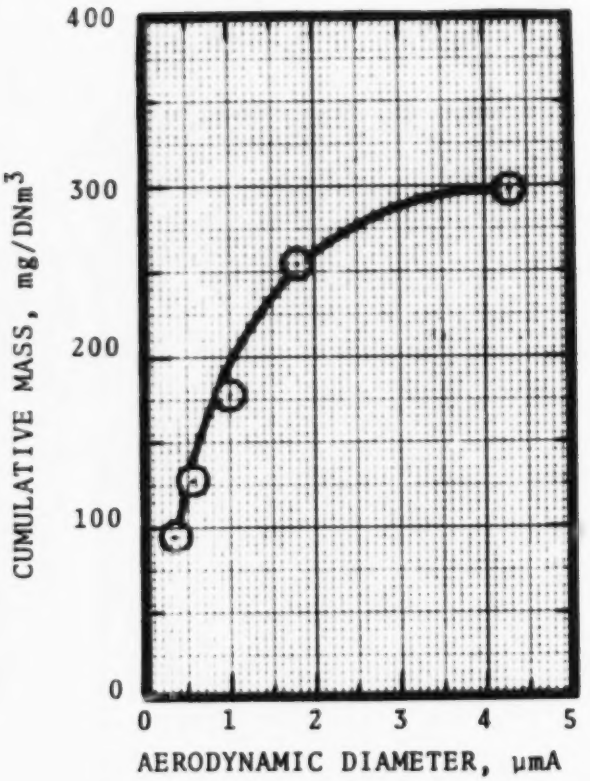

Figure B-1 - Cumulative inlet mass concentration for Run #10

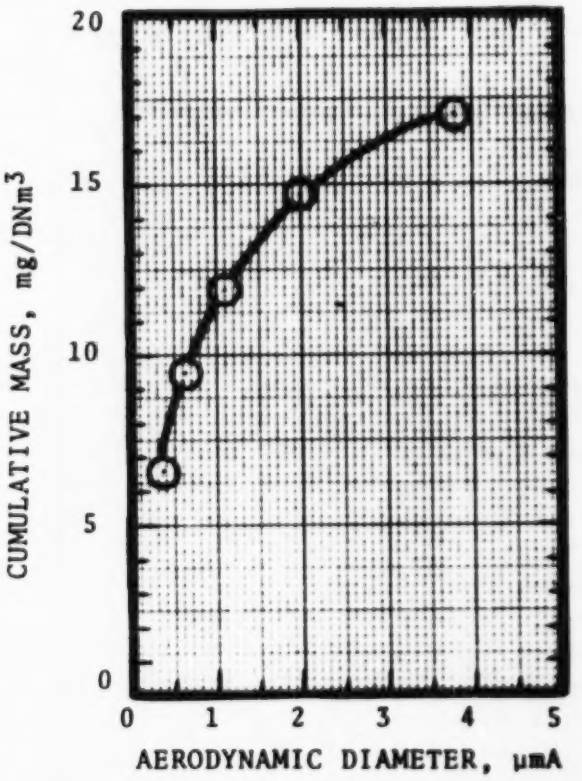

Figure B-2 - Cumulative outlet mass concentration for Run #10

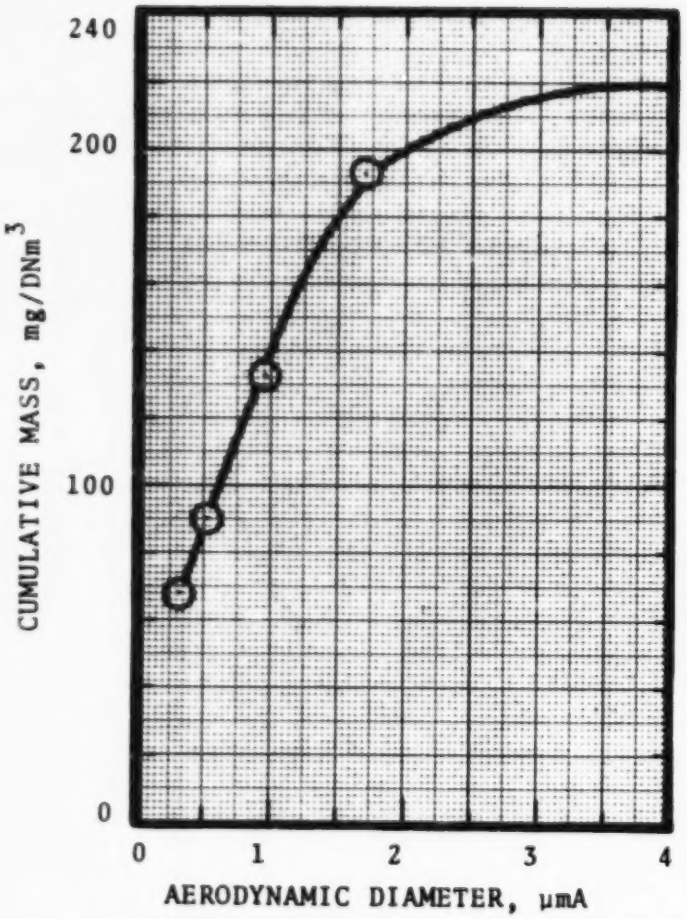

Figure B-3 - Cumulative inlet mass concentration for Run #11

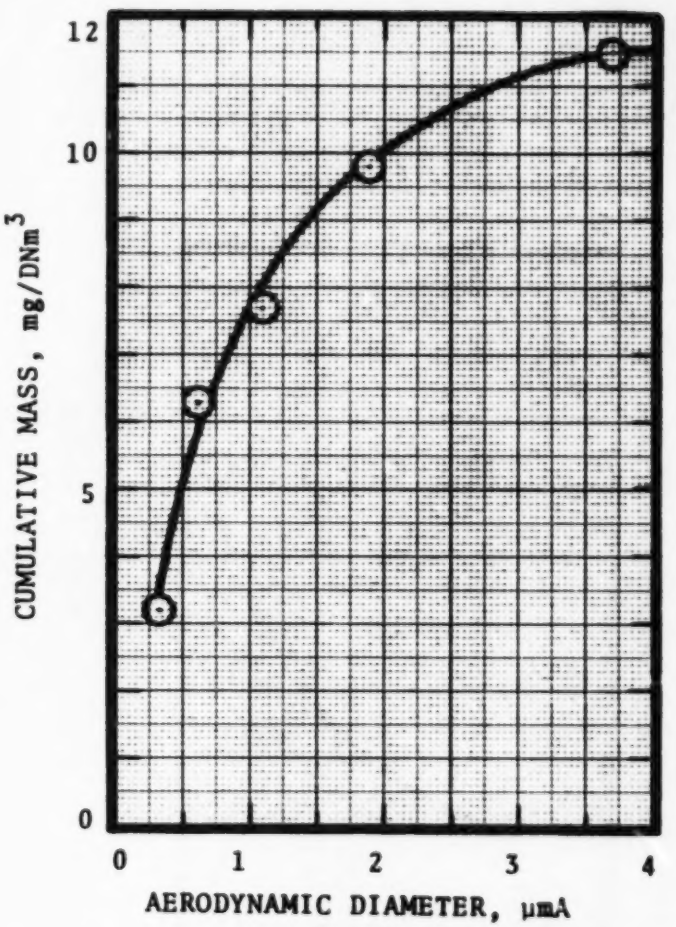

Figure B-4 - Cumulative outlet mass concentration for Run #11

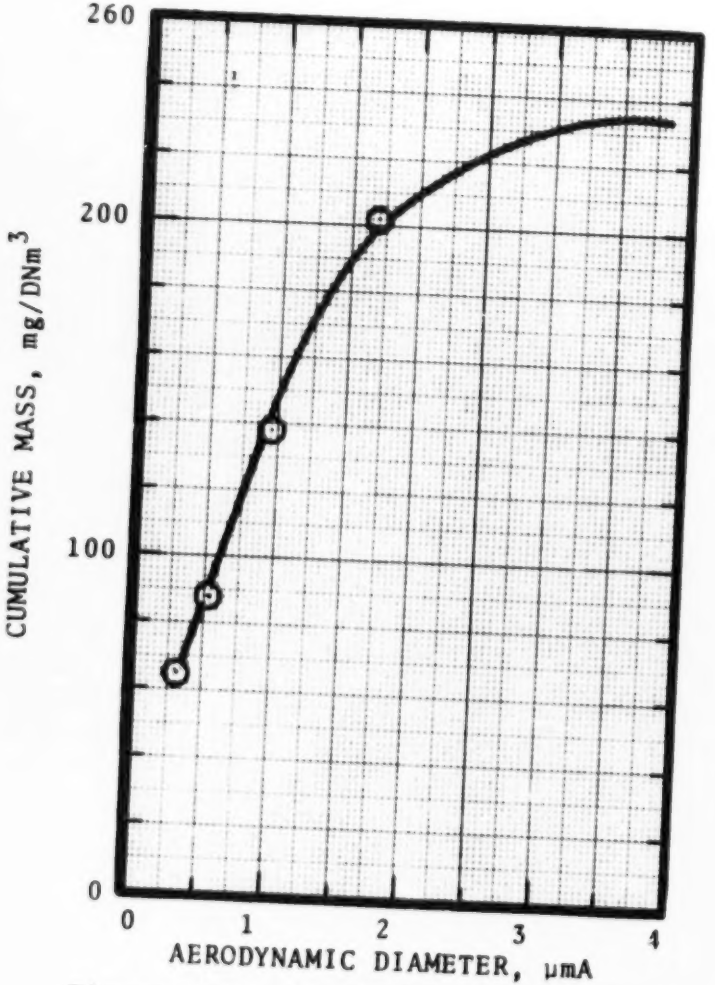

Figure B-5 - Cumulative inlet mass concentration for Run #12

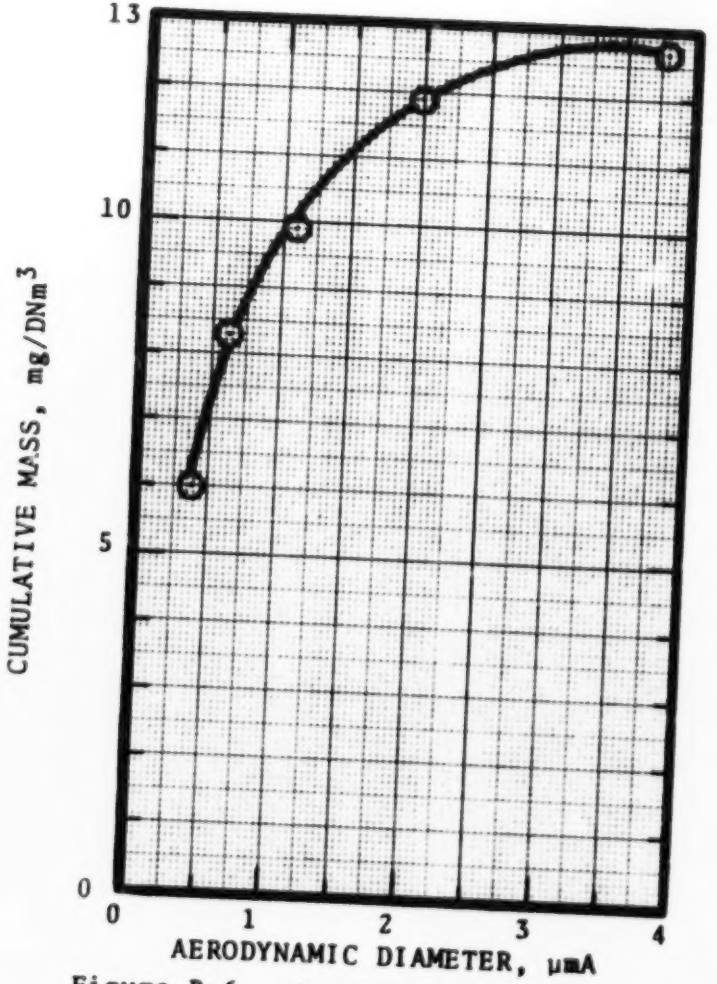

Figure B-6 - Cumulative outlet mass concentration for Run #12

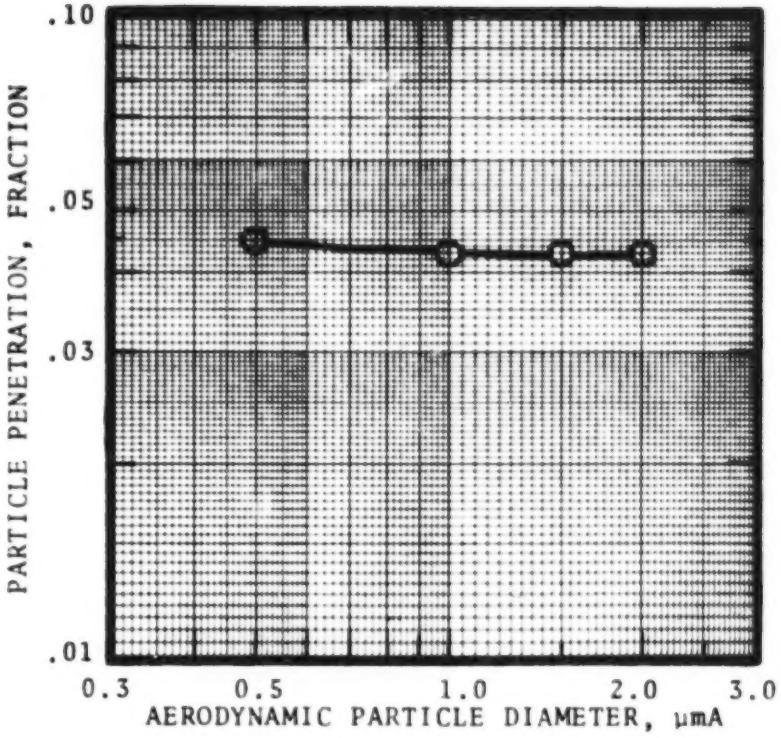

Figure B-7 - Penetration versus dry particle diameter for Run 10

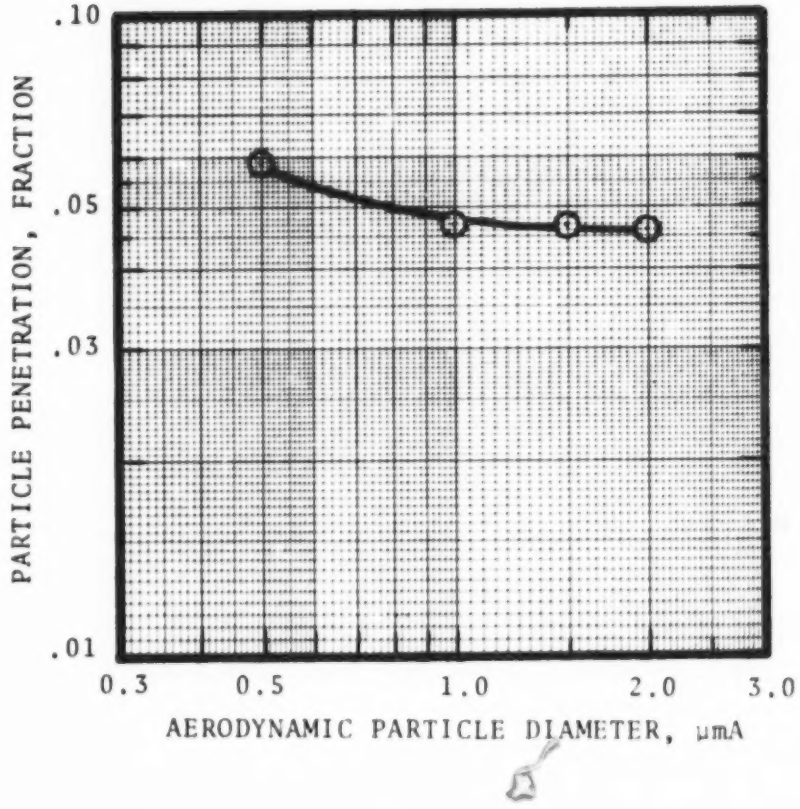

Figure B-8 - Penetration versus dry particle diameter for Run 11

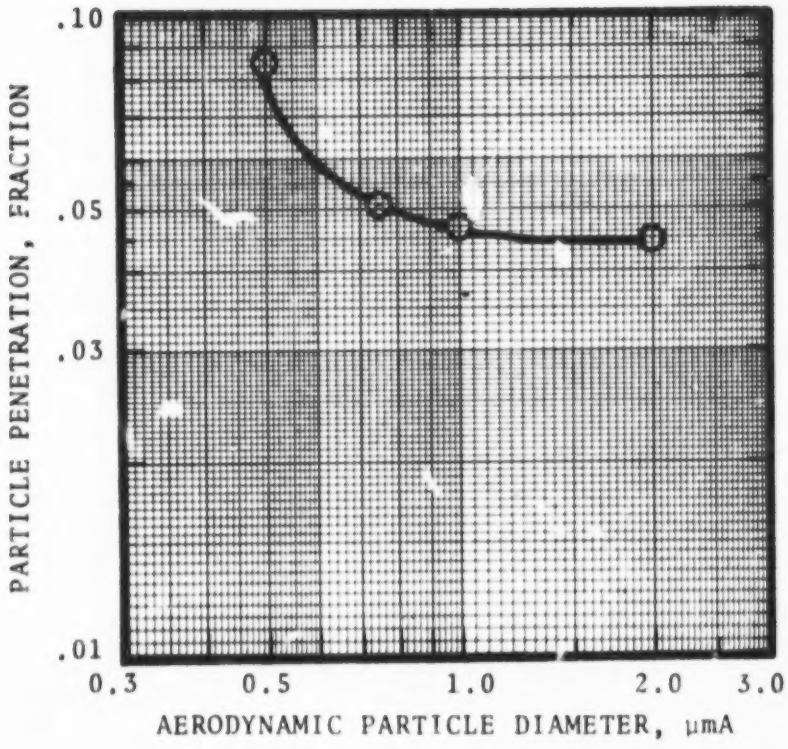

Figure B-9 - Penetration versus dry particle diameter for Run 12